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ON THE CHARGE DEPENCENCE OF FACTORIAL MOMENTS IN e^+e^- PROCESSES [1]

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ABSTRACT

The behaviour of like-charge and unlike-charge second factorial moments in e^+e^- reactions is discussed. It is argued that Monte Carlo calculation with the help of generators JETSET 7.4 and HERWIG 5.8 points to the conclusion that the only nontrivial cause of intermittency are Bose-Einstein correlations of identical particles.

Since the original proposal of Bialas and Peschanski [1], factorial moments (as well as more general quantities of the same character [2]) have become a widely accepted tool in studying multiparticle final states in various processes. Let us define the i-th factorial moment as

$$F_i = \frac{1}{N_{events}} \sum_{events} \frac{\sum_{k=1}^{n_{bins}} \left\{ n_k(n_k-1)\cdots(n_k-i+1) \right\}/n_{bins}}{(\langle n \rangle / n_{bins})^i} \qquad (1)$$

where $\langle n \rangle$ is the average number of particles in the full phase space region accepted, b_{bins} denotes the number of bins in this region, which is given by $(2^b)^d$, $b = 0, 1, 2...$ (d is the dimension of the phase space region considered) and n_k is the multiplicity in k-th bin. In what follows I will consider factorial moments in two and three phase-space dimensions, in the conventional variables (y, φ) and $(y, \varphi, \tilde{p}_t)$ (y denotes rapidity, taken here from the interval $(-3.2, 3.2)$, φ is the azimuthal angle and $\tilde{p}_t$ is the "flattened" momentum transverse defined as [3]

$$\tilde{p}_t = \frac{\int_0^{p_t} P(p)dp}{\int_0^{p_t^{max}} P(p)dp} \qquad (2)$$

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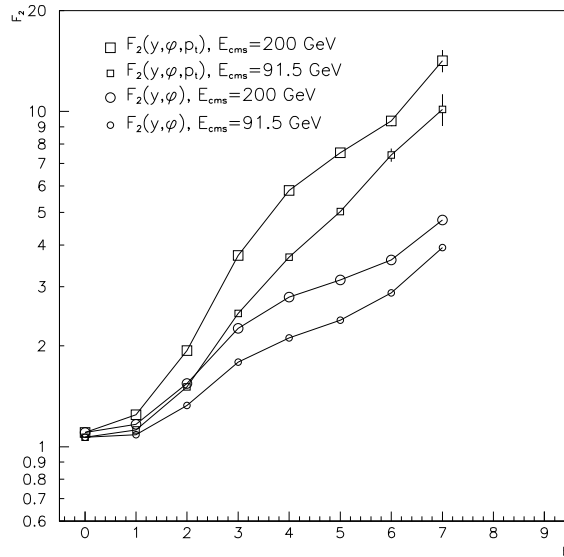
Figure 1: Factorial moments F_2, for two and three phase space variables (see text), calculated by JETSET 7.4 for C.M.S. energy 91.5 GeV and 200 GeV

where $P(p_t)$ is the probability distribution of p_t in the interval $(0, p_t^{max})$ and p_t^{max} was chosen as 2 GeV/c. Rapidity and p_t are expressed with respect to the thrust axis. The moments are calculated from the charged particles in final states only.

The behaviour of factorial moments plotted as a function of bin size (i.e. b in our notation) provides information about the character of multiplicity fluctuations among different bins. Rising of F_i with rising b (decreasing bin size) generally signalizes deviation from purely Poissonian distribution of fluctuations. The linear growth of $\log F_i$ with b was called intermittency by the authors of [1]. Nowadays, the term is often used for any type of growth of F_i observed.

The purpose of this talk is to discuss the effect of intermittency in e^+e^- physics in the context of Monte Carlo (MC) generators. MC event generators provide a computational device in a situation where one based purely on the first principles is lacking. They use a combination of theoretically based calculations on the level of partons and purely phenomenological (though with sound qualitative theoretical motivation) description of the hadronization phase. Obviously, MC generators are not physics, but for the present discussion they have one important advantage — they allow one to switch on and off different particular processes, both on the level of partons and on the level of hadronization and hadronic decays, and thus to pinpoint in greater detail the causes of different effects — something which is not possible in the real world.

In what follows I will discuss the results obtained with the help of two of the most widely used e^+e^- MC event generators — JETSET 7.4 [4] and HERWIG 5.8 [5]. The

aim is to find out what can be said about the behaviour of factorial moments on the basis of MC generation of events and, also, how the results of both abovementioned generators compare.

The event generators for e^+e^- physics are generally considered to be in a very good shape. Unlike in other types of reactions, the agreement with the real data had been reported not only for various one–particle distributions, but, in some cases, also for multiparticle quantities like factorial moments. At first sight, this seems not to be surprising, as in e^+e^- processes everything is much "cleaner" than in other cases (no need of introducing phenomenological parton distributions in the initial states, no "nonperturbative" low p_t hadronic interactions etc.). On the other hand, if, as is now increasingly believed, the major part of intermittent behaviour is solely due to Bose-Einstein (BE) correlations [6] of identical particles (for a rewiev see e.g. [7]), this observation deserves some other discussion — as there are no true BE correlations included in MC generators (more on this see below).

Both of the generators mentioned above use a QCD motivated description of the partonic stage of the process, so that it is possible to address, at least in principle, the question whether intermittency is due to some sort of partonic branching (as, for example, descriptions based on local parton-hadron duality (LPD) [8] claim), or whether it is the result of some other mechanism. The question had been partially answered in [9], where it is stated that there is no LPD present either in JETSET or in HERWIG — although the generators are considerably different on the level of partons, in terms of final hadrons they yield almost identical results not only for various one-particle distributions, but also rising behaviour for factorial moments. In this talk, I will discuss this problem further.

Fig.1 shows the second factorial moment F_2, both for two-dimensional and for three-dimensional case, calculated with the help of JETSET 7.4, as a function of bin size characterized by b. In both cases one observes clear rising behaviour. The question is what is the cause of this behaviour: One can be sure (in contrast to real data) that there are no BE effects included in the MC calculation, while direct effect of partonic branching is strongly disfavored [9]. It is clear that more information can be obtained if one looks at the moments for like-charge and unlike-charge combinations of particles separately — in the like-charge quantities the BE correlations may play their role (though, I repeat, not in the MC calculations presented here), while in an unlike-charge factorial moment the influence of BE correlation is principially excluded. The second factorial moments for like charge pairs are defined in an obvious way — e.g., for plus-plus combination as

$$F_2^{++} = \frac{1}{N_{events}} \sum_{events} \frac{\sum_{k=1}^{n_{bins}} \left\{ n_k^+ (n_k^+ - 1) \right\} / n_{bins}}{(\langle n^+ \rangle / n_{bins})^2} \tag{3}$$
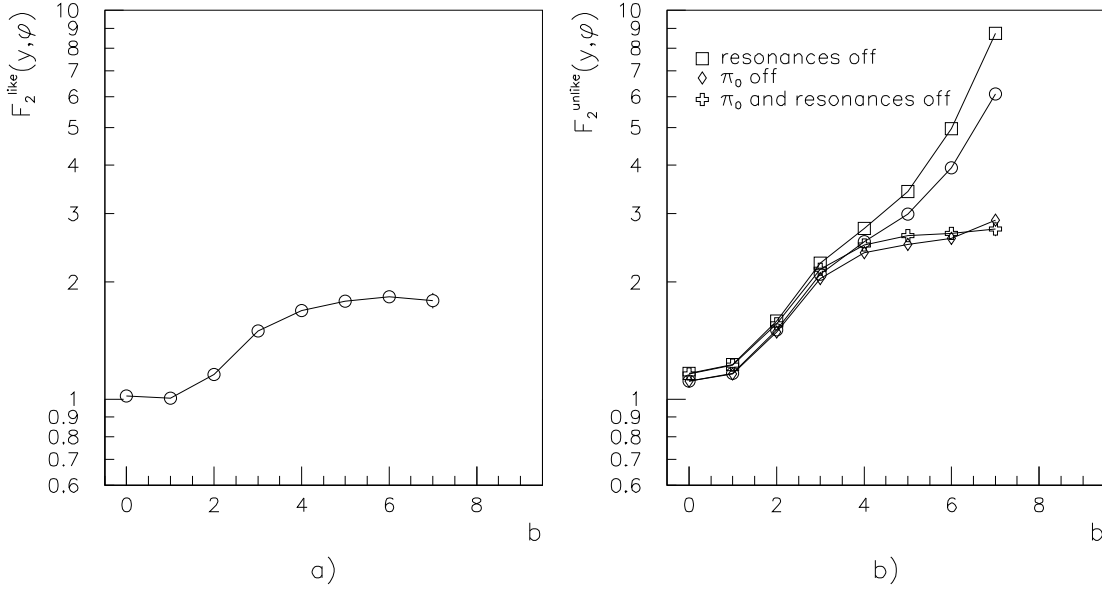
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Figure 2: Factorial moments $F_2(y, \varphi)$ for like-charge (a) and unlike-charge (b) combinations, calculated by JETSET 7.4 for C.M.S. energy 91.5 GeV. Figure (b) illustrates the influence of resonance decays and π_0 decays.

and analogously for minus-minus. For unlike charges I use the definition

$$F_2^{+-} = \frac{1}{N_{events}} \sum_{events} \frac{\sum_{k=1}^{n_{bins}} \left\{ n_k^+ n_k^- \right\} / n_{bins}}{\langle n^+ \rangle \langle n^- \rangle / (n_{bins})^2} \tag{4}$$

Fig.2 shows the behaviour of two-dimensional factorial moments at the centre-of-mass energy 91.5 GeV, calculated with the help of JETSET generator. One can see that the like-charge moment shows a clear plateau (if BE correlations are the real cause of intermittency, one should expect the rise of this quantity for the real data — a conclusion supported e.g. by [10] (which, however, analyses not factorial moments but two-particle correlation functions), while all the observed rising behaviour is in the unlike-charge function.

   An obvious candidate to cause this type of behaviour is the decay of resonances in the unlike-charge channel. However, the line on Fig.2b, corresponding to the calculation with several major resonances ($\rho_0, \eta, \eta', \eta_c, \omega, B, J/\psi$) switched off in the generator, shows that this is not the case. On the other hand, there is a clear plateau on the line corresponding to π_0 decays switched off. The only important unlike-charge decay products of π_0 decay are e^+e^- Dalitz pairs. The rising of unlike-charge two-dimensional second order factorial moments (as well as that part of all-charge moments rising which is not caused by BE correlations) is thus due to Dalitz pairs. The line in Fig.2b corresponding to both π_0 and resonance decays switched off shows that for two-dimensional moments, resonance decays do not play any important role
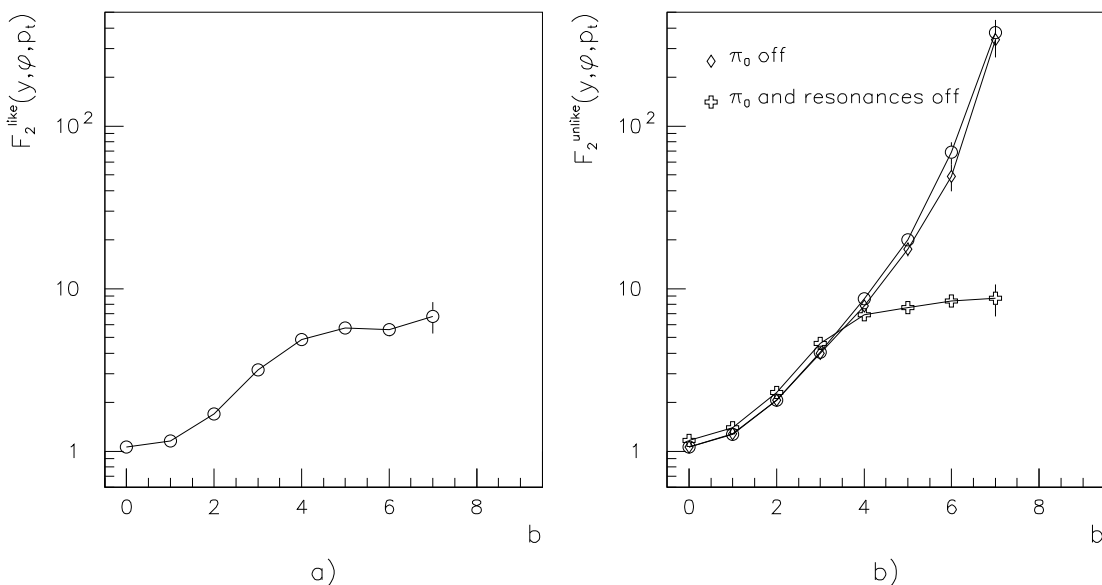
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Figure 3: Factorial moments $F_2(y, \varphi, \tilde{p}_t)$ for like-charge (a) and unlike-charge (b) combinations, calculated by JETSET 7.4 at C.M.S. energy 200 GeV.

in the phenomenon of intermittency.

The same quantities, but this time for the three-dimensional case in the variables y, φ and $\tilde{p}_t$, are depicted in Figs.3a, 3b. As Fig.3a shows, for like-charge FM the situation is much the same as for two dimensions. For the unlike-charge combinations, there is, however, one difference — to "stop" the rise of the quantity, one has to switch off both π_0 decays and resonances. This is another demonstration of the well known fact that the most detailed information is provided by three-dimensional factorial moments, while in lower dimensions things may "project out".

To summarize this part, from the analysis based on the calculations with the generator JETSET 7.4 it follows that the only cause of the intermittent behaviour of factorial moments, with the possible (and probable) exception of BE effects, are various decays of known hadrons. How do the predictions of HERWIG 5.8 look like in this respect?

Fig. 4a shows a comparison, for the two-dimensional moment, between a calculation done by JETSET and HERWIG, respectively. There is a clear difference — the curve corresponding to HERWIG shows a plateau. In view of the previous experience, however, one can suspect that the situation looks very much like in JETSET with π_0 decays switched off. Indeed, one finds out that the decay mode of π_0 into e^+e^- pair is not included in the hadronic decays of HERWIG 5.8. If this situation is "corrected" by switching of π_0 decay in JETSET, a good agreement between the predictions of the two generators is obtained (fig. 4a, line of triangles). Figs. 4b and 4c show the comparison of JETSET and HERWIG predictions for like-charge and unlike
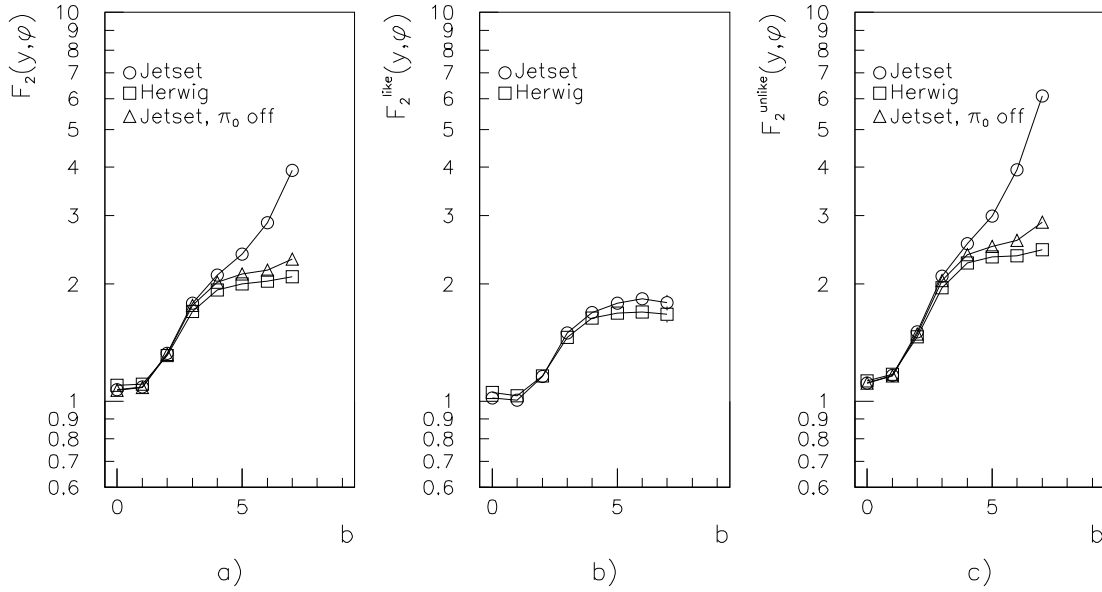
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a) $F_2(y,\varphi)$ — ○ Jetset, □ Herwig, △ Jetset, π_0 off; axis b

b) $F_2^{like}(y,\varphi)$ — ○ Jetset, □ Herwig; axis b

c) $F_2^{unlike}(y,\varphi)$ — ○ Jetset, □ Herwig, △ Jetset, π_0 off; axis b

Figure 4: Comparison of two-dimensional factorial moments F_2 calculated by JET-SET 7.4 and HERWIG 5.8 for $E_{CMS} = 91.5$ GeV

charge moments separately. They confirm the conlusion that the only (but, as we have seen, importatnt for the behaviour of factorial moments) disagreement is in the non-inclusion of Dalitz decays of π_0 mesons in HERWIG. Otherwise, both generators give very similar results, much the same way as for the one-particle distributions.

The same conclusion follows from the comparison of three-dimensional factorial moments (not shown here).

In the JETSET generator, there is an option to include the effect of BE correlations. Of course, no generator can incorporate true BE correlations, as generators do not describe coherent effects in hadronization. In JETSET, the BE option consists in modification of two-particle distribution of identical particles in the Q^2 variable (where $Q^2 = -(p_i - p_j)^2$) according to certain weight. It is nevertheless interesting to find out how the factorial moments from JETSET look like with BE correlations option switched on. This is shown on Fig.5: The JETSET option of including BE correlations has no apparent influence on the character of behaviour of like-charge factorial moment. This is seemingly in disagreement with what is stated in some analyses. The whole point, however, is that the analyses which report increased agreement between MC generation and measured quantities after inclusion of BE option in JETSET (e.g. [10]) are precisely those which use variables like Q^2 or m^2 (the invariant mass of the pairs). Throughout this discussion, however, I used the "old fashioned" way of expressing factorial moments in separate phase-space variables. It is not surprising that the method of inclusion BE correlations which is tailored to the Q^2 variable works reasonably well with functions of this same variable but fails in
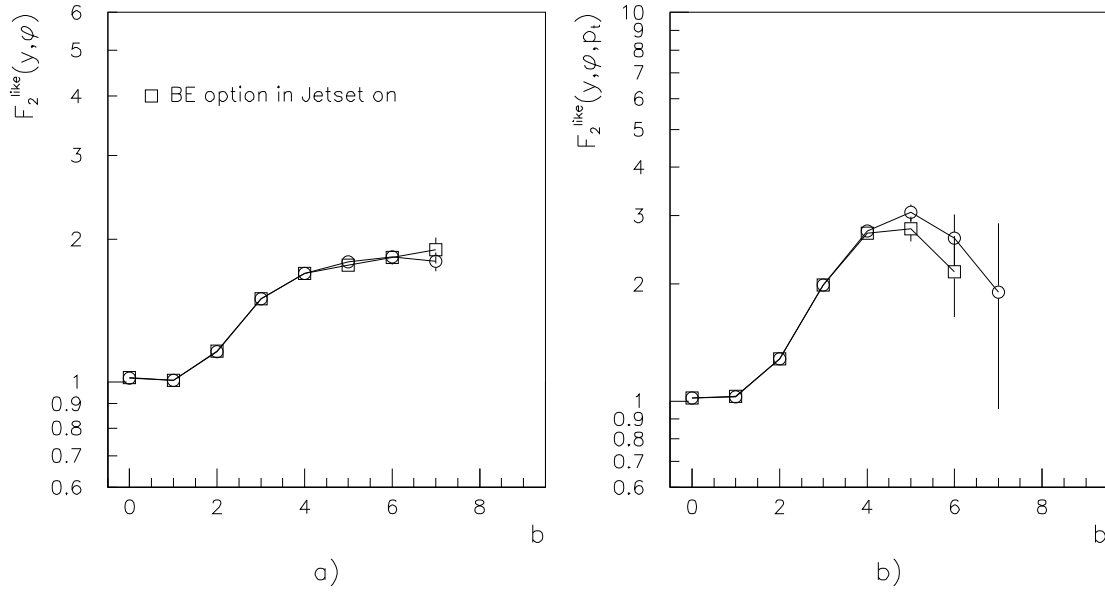
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Figure 5: Factorial moments F_2 for unlike-charge combinations, calculated by JET-SET 7.4 without and with the Bose-Einstein option. $E_{CMS} = 91.5$ GeV

other cases. As mentioned above, truly general description of BE correlations within the generators is, up to this moment, lacking.

In summary, the present analysis leads to following conclusions:

- The calculation of two- and three-dimensional second factorial moments based on the MC event generators JETSET 7.4 and HERWIG 5.8 supports the view that all the intermittency (i.e. rising behaviour of factorial moments) in e^+e^- reactions is due to either BE correlations of identical hadrons or known effects as decays of particles. Especially important is the role of decays of π_0 mesons into e^+e^- Dalitz pairs. No new mechanism is present.

- The generators used for the calculation yield very similar results (apart from the trivial technical detail that a decay mode important for the effect studied, the π_0 decay into Dalitz pairs, is not included in HERWIG). Apart from the importance of the fact itself, this leads to an immediate conclusion concerning local parton hadron duality: One can hardly imagine that something like local parton hadron duality is present in the generators used, as both of them differ quite considerably on the parton level [9]. In a sense, the hadronisation in the generators considered has just the opposite property, being highly nonlocal.

- The effect of BE option in JETSET on the calculated quantities is highly dependent on the type of quantities and, especially, variables used. In the case discussed (factorial moments as functions of separate non-invariant phase-space variables) the inclusion of BE option shows little influence on the character of

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behaviour of factorial moments. This fact is hardly surprising, in view of how BE effects in JETSET are treated [4].

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